

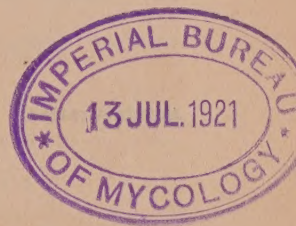
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MASSACHUSETTS  
AGRICULTURAL EXPERIMENT STATION

ELECTRICAL INJURIES X  
TO TREES

By GEORGE E. STONE



This bulletin deals with electrical injuries to trees, including a brief discussion of the electrical resistance in trees, as well as the effects of alternating and direct currents, lightning and earth discharges. The methods of preventing injury to trees from wires are also discussed.

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# ELECTRICAL INJURIES TO TREES.

GEORGE E. STONE.

## INTRODUCTION.

In 1903 there was issued from this station a bulletin dealing with some new phases of the subject of electrical injury to trees.<sup>1</sup> This bulletin has been out of print for some time, and as many new observations—the result of years of careful study of the influence of electricity on plants—have been made, it has been thought wise to issue another edition. Many people are quite unfamiliar with certain types of injury from electricity occasionally to be found, and even those directly responsible often do not realize how serious the harm done is likely to prove.

The increase in electric railroads, electric lighting systems and telephone lines, whose wires are usually located near the tree belts of our cities and towns, has made necessary a lamentable amount of disfiguring pruning. When strung too close to trees, wires also often cause serious injury by burning, and sometimes mechanical injury is done; and even lightning discharges will cause harm when guy wires are attached to trees. (See Fig. 1, Plate I.)

Both the alternating and direct currents are used. They produce different physiological effects on plant life, the alternating current apparently being less injurious than the direct; and when either is used at a certain amperage it acts as a stimulus to the plant, and growth and development are accelerated.

There are minimum, optimum and maximum currents affecting plants. The minimum represents that strength of current which just perceptibly acts as a stimulus, and is a very insignificant current. The optimum is that producing the greatest stimulus—about .2 milliamperes—and the maximum, that causing death. (See Fig. 3.) Between the optimum and the maximum there is a strength of current that causes retardation in the plant activities, this being represented between R and MX in Fig. 3. The maximum current necessary to cause death is very variable. The direct current has a less stimulating effect than the alternating, and on account of its electrolyzing effect is capable of causing more injury to vegetable life than the alternating current.

Most of the injury to trees from trolley or electric light currents is local; *i.e.*, the injury takes place at or near the point of contact of the wire with the tree. This injury is done in wet weather when the tree is covered with a film of water, which provides favorable conditions

<sup>1</sup> G. E. Stone, "Injuries to Shade Trees from Electricity," Bul. No. 91, Mass. (Hatch) Agr. Exp. Station, 1902.

for leakage, the current traversing the film of water on the tree to the ground. The result of contact of a wire with a limb under these conditions is a grounding of the current and burning of the limb due to "arcing." The vital layer and wood become injured at the point of contact, resulting in an ugly scar and sometimes the destruction of

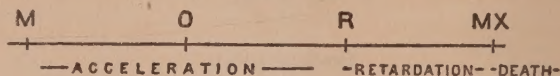


FIG. 3.—Diagram showing range of electric current affecting plants. M=minimum; O=optimum, or current producing greatest stimulus; MX=maximum, or death current; R to MX=retardation current

the limb or leader. In a large number of tests made by the aid of sensitive instruments with guy wire and other connections of wires to trees we have never found any leakage during fair weather, or when the surface of the tree is dry. Since the amount of current that can be passed through a tree depends upon the resistance and electro-motive force, we shall consider this resistance at some length.

#### ELECTRICAL RESISTANCE OF TREES.

The electrical resistance shown by trees is quite great, otherwise more injury might result from contact with live wires. The following table (I.) gives the electrical resistance of 10 feet of a maple and elm, each tree being about 2 feet in diameter and the electrodes 10 feet apart. These resistances were determined by a Western Electric Company combination bridge rheostat and galvanometer, and a large battery. Other resistances, however, have been obtained by means of the electro-motive force, and a known current passed through the tree, the two methods agreeing in their results quite closely. The table, which is taken from one of our previous publications,<sup>1</sup> is one of many.

TABLE I.—*Showing Average Electrical Resistance (in Ohms) of Maple (Acer saccharum Marsh) and Elm (Ulmus americana L.) covering a Period of nearly Three Months. Resistances taken on the North, South, East and West Sides of the Trees about Midday. Electrodes 10 Feet Apart.*

TREE.	Month.	East.	South.	West.	North.
Maple,	April,	18,550	18,185	20,500	20,800
	May, . . . . .	21,075	20,550	21,650	24,500
	June, . . . . .	19,775	19,761	21,883	22,550
Elm, . . . . .	April,	24,300	26,075	25,700	24,275
	May, . . . . .	13,025	15,750	14,825	17,375
	June,	14,992	18,608	17,508	17,883

<sup>1</sup> Electrical Resistance of Trees, G. E. Stone and G. H. Chapman, 24th Ann. Rept. Mass. Agr. Exp. Station, 1912, Pt. I., p. 144.



It will be noted that these resistances were taken on the east, south, west and north sides of the trees, and represent averages of weekly observations. The lowest resistance (data not given in the table) obtained from the maple was 14,000 ohms, and the highest, 33,000 ohms. In the case of the elm the lowest resistance was 6,300 ohms, while the highest was 29,400 ohms. These resistances are relatively low, for in cold weather they often exceed 100,000 ohms. The lower resistance in all cases corresponds to periods of high temperatures, and the highest to periods of the lowest temperature. The difference shown by the various sides of the tree is also related to temperature.

As might be expected, there is considerable difference in the electrical resistance of various trees as well as of the different tissues found in trees. The heartwood, sapwood, cambium, bark and sieve tubes possess quite different properties and functions, and their electrical resistance would naturally vary to a large extent. The living cells containing protoplasm, such as are found in the cambium, present the least resistance, as shown by various observations on lightning discharges. The minute burned channel, caused by comparatively insignificant lightning discharges, follows down the cambium, indicating that this is the line of least resistance. Moreover, by driving electrodes into a tree to different depths and measuring the resistance it can be shown that the least resistance occurs in the region of the cambium.

The electrical resistance, however, may average throughout the year 25,000 ohms more or less in 10 feet of the trunk of a large maple tree. This constitutes a comparatively high resistance. The resistance of the sapwood is very much greater, and probably that of the heartwood is even higher than that of the sapwood.

In determining the electrical resistance it is necessary to know the path or course of the current, and the only manner in which the resistance of different tissues can be determined accurately is by isolating the tissues. By girdling a tree and scraping the trunk down to the solid wood we can get the resistance of the wood. Mr. G. H. Chapman found the resistance of a freshly cut rock maple stem,  $1\frac{1}{2}$  inches in diameter, to be 70,000 ohms with the bark on, but 150,000 ohms when the bark was removed. The electrodes were 1 foot apart. Some of our experiments indicate that next to the cambium the phloem has the least resistance, followed by the sapwood. The outer bark appears to offer the most resistance, but when wet the resistance may be somewhat decreased owing to the less resistant film of moisture on the bark. The resistance obtained from an elm tree in summer, with the electrodes 10 feet apart and in contact with the cambium, was 10,698 ohms, whereas when the electrodes were inserted into the middle of the cortex or phloem we obtained 11,300 ohms resistance. When driven  $\frac{1}{4}$  inch into the wood the resistance was 98,700 ohms. The outer bark gave 198,800 ohms resistance, but when the electrodes were inserted slightly

deeper into the bark we obtained 109,900 ohms. It must not be understood, however, that these readings gave the electrical resistance of 10 feet of the various tissues enumerated except in the case of the cambium, since if these tissues were isolated the resistance would be much greater in some cases. They show that there is much difference in the resistance of different tissues, but in all cases we obtained merely a resistance of the cambium, together with that of a part of the other tissues which the current had traversed from its various points of entrance to the cambium. It is quite evident from our observations on the resistance of trees that the cambium gives the least resistance, the phloem next, and it is not at all unlikely that in some trees there may be some variation in this respect.

The resistance given by small tree trunks and woody stems, even for small distances, is quite large. About 4 feet of a young pear tree, including the root system, with a maximum diameter of stem equal to 1 inch, gave a resistance of about 300,000 ohms, and the resistance given by a tobacco plant, in which the distance between the electrodes was only 14 inches, was much higher (110,000 ohms to 165,000 ohms) than that shown by most trees at corresponding temperatures.

The water and various salts in the living plant undoubtedly play a rôle in resistance, and it might be expected that the various plastic substances would influence resistance.

The cambium ring is very insignificant in size, and even on a large tree the total area is small. In all probability it is the protoplasm itself which offers the least resistance to the transmission of an electric current; and even if there were no continuity it would be necessary for the current to pass through a great many cell walls even for comparatively short distances on the trunk. In case the protoplasm was continuous or there existed continuity, the strands would be so very small that they would undoubtedly offer some resistance. Whatever conditions prevail, trees show relatively high electrical resistances, a feature which is no doubt of some biological importance as trees are often struck by lightning. The high resistance of trees, therefore, is undoubtedly a protection in case of lightning strokes, since often the heat developed is enough to do only slight injury. On the other hand, if trees possessed tissue with relatively small electrical resistance they would be much more subject to injuries from burning from lightning strokes, and would be more seriously affected by currents from high-tension wires. The electrical resistance of trees is so high that it is doubtful whether injury ever occurs to them from contact with low- or even high-tension wires except that produced by grounding when the bark is moist. Any escaping current from transmission lines that can be transmitted even through the least resistant tissue is likely to be insignificant.



## EFFECTS OF ALTERNATING CURRENTS.

The alternating current systems employed for lighting purposes vary greatly in their potential. Cases of burning from alternating currents are more numerous than those from direct currents because trees are brought into more frequent contact with the wires, and owing to the higher potential more leakage is likely to occur. The high and low voltage lines may vary from 100 to 100,000 volts. The high-tension systems are invariably constructed across country, and are naturally not brought into very close proximity to shade trees. No injury to trees whatever occurs from the low voltage (110-volt) lines, but the lines of higher potential found on streets constitute a source of danger to trees. The higher the electrical potential the more dangerous the wires become to trees, for owing to the lessened effectiveness of the ordinary insulation, more leakage occurs and consequently greater opportunity for burning.

The effects of alternating currents on trees are local, producing injury only near the point of contact with the wire. Such contact results in death of that part of the tree, and if it is a leader or a large limb it usually has to be sacrificed. In no case, to our knowledge, has an alternating current caused the death of a tree, although it may burn or disfigure the tree so badly that it amounts to practically the same thing. It is doubtful whether the current from a fairly high potential wire would kill a large tree under any circumstances. It is different in the case of small plants, as has been frequently demonstrated in the laboratory, although the current must produce heat enough to kill the protoplasm. Owing to the close relationship between the maximum temperature required to kill a plant and that induced by electrical current, the collapse of the plant tissue in such cases is therefore due to the heat rather than to any specific electrical shock, as it is possible to pass the same current through larger plants where heat is not generated without causing any collapse of the tissue. The ordinary house circuit wires are perfectly harmless to trees, and it seems strange that a judge could render a verdict to the effect that an ordinary insulated 110-volt house circuit was responsible for the death of a tree whose terminal branches were located within 3 feet of it. This is the only court record of which we know where such a judgment has been given.

Very high-tension line wires are not provided with insulation and are known to affect the atmosphere surrounding them to a considerable extent. Any increase in the electrical potential of the atmosphere if not too high would favorably affect vegetation in general.<sup>1</sup>

<sup>1</sup> There is evidently much difference in plants in this respect. A crop of radishes showed a gain of 57 per cent. when subjected to an average atmospheric potential of 167 volts, whereas an electrical potential equal to 500 or 1,000 volts is beyond the stimulation zone for some plants (16th Ann. Rept. Mass. Agr. Exp. Station (Hatch), 1904, p. 31).

It has been suggested that arc lights are injurious to trees, although we have never seen any cases of injury. It is well known that electric light is different from sunlight in its effects on plants, and it stimulates photosynthesis in proportion as it resembles sunlight in its rays. Some artificial lights contain rays that may act injuriously on small plants and in other ways modify their development, but even if a tree in close proximity to such a light should die it is no proof that it has been injured by this cause, as there are so many other causes for the death of trees.

#### EFFECTS OF DIRECT CURRENTS.

Most of the direct currents affecting trees are those used for operating electric railroads. Trolley feeders may be at 500 to 550 volts. Ordinarily the burning from direct currents is similar to that produced by the alternating current in being largely local or confined mainly to the point of contact with the wires. The feed wires cause no burning except when the tree is moist, in which case grounding takes place.

We have made a number of experiments, using large trees and small herbaceous plants, with direct currents from electric railroads showing the amount of current passing through trees, etc. In a number of instances a wire was passed from the tree to the rail or ground, and another wire was connected to a bare feed wire (450 to 500 volts) leading to some other portion of the tree, a milliammeter being placed in the circuit to obtain the actual current. The results were as follows: a young pear tree, 2 feet 8 inches in height, and  $1\frac{1}{4}$  inches in diameter at the base, which had been growing one year in a box 14 by 16 by 9 inches, and provided with a copper plate in the bottom in direct contact with the roots, showed a current of 2.2 milliamperes ( $\frac{1}{454}$  ampere) when one electrode leading to the rail was connected with the copper plate, and the other leading to the feed wire joined the top of the tree;  $16\frac{1}{2}$  feet of a maple tree 18 inches in diameter gave 25 milliamperes ( $\frac{1}{40}$  ampere), and 7 feet of the same tree gave a current of 45 milliamperes ( $\frac{1}{22}$  ampere). Connections made with a poison ivy (*Rhus toxicodendron* L.) plant growing on a tree showed in most cases similar results when the electrodes were inserted into the stem 2 inches apart. A stem  $\frac{3}{4}$  inch in diameter gave a current equal to 4.4 milliamperes ( $\frac{1}{227}$  ampere);  $\frac{1}{2}$  inch in diameter, 25 milliamperes ( $\frac{1}{40}$  ampere); and another of the same size, 50 milliamperes ( $\frac{1}{20}$  ampere). In the latter case, and some others not included here, the currents went down from 50 milliamperes to nothing almost instantly. From these experiments with ivy it appears that the current burned out the cambium or vital layer of the stem, leaving the dry and highly resistant wood which was unable to transmit a perceptible current.

In another experiment young sunflowers and tomato plants grown in 3-inch pots, with copper plates at the bottom, were treated from a

direct current dynamo which generated an electro-motive force of about 60 volts. The plants were from 6 inches to  $2\frac{1}{2}$  feet high, and  $\frac{1}{8}$  to  $\frac{1}{4}$  inch in diameter. When the current passed through 16 inches of the stem and copper plate to the bottom of the pot, a sunflower plant  $\frac{3}{16}$  inch in diameter gave scarcely perceptible readings; but when the current passed through only 1 inch of the stem and root to the copper plate at the bottom, the maximum current was  $\frac{3}{4}$  milliampere ( $\frac{1}{84}$  ampere). This caused blackening and death of the tissues, perceptible a few hours afterwards about the points of insertion of the positive electrodes into the stem, and the plant was girdled for about two-thirds of its circumference. Very similar results were obtained with other sunflower plants treated in the same way. A plant 30 inches high and  $\frac{1}{4}$  inch in diameter, subjected to a current of 10 milliamperes for some minutes, was not injured to any extent. In this case the current passed through about 1 inch of stem and  $\frac{1}{2}$  inch of soil. A young, succulent tomato plant,  $\frac{1}{8}$  inch in diameter and 5 inches high, was instantly killed when treated in the same manner with a current of 20 milliamperes, and a current of 2 and 3 milliamperes of 30 to 60 seconds duration accomplished the same result. In all the tomato plants considerable heat was developed. In one case in which an alternating current was used the plant lived for a number of days after the tissues had changed color and the plant had collapsed, as the vascular bundles or water-conducting tissues were not injured.

In the experiments cited all the injuries occurring were due to the effects of heat generated by the current. The experiments also showed that the strength of current which will kill one plant will produce not the slightest effect on another; in other words, the maximum current for each individual varies materially. Small, tender plants possess a maximum much below that of woody plants. The experiments were all carried on under normal moisture conditions; but when trees with a more or less thick bark are drenched with rain the conditions are quite different. A large maple tree which was in circuit with a feed wire (500 volts) and rail of an electric road gave a current equal to 70 milliamperes ( $\frac{1}{4}$  ampere) with the electrodes placed vertically 1 foot apart. These connections were left on the tree for several months. The observations were made on dry days, and no heat developed with this current. During periods of wet weather considerable heat always developed, especially at the positive electrode, but not enough to melt the soft solder which connected the wires with the electrodes.

Examination of the tree ten months later showed that a portion of the tissues near the electrodes had been killed. After removing the dead bark an oval space 6 by 11 inches was found to be dead about the positive electrode and a space about  $1\frac{1}{2}$  by 3 inches near the negative electrode. The burned area about the positive electrode was about



95 per cent. greater than that occurring about the negative electrode. In each case it extended about twice as far above and below the point of contact as out to the sides of the electrodes, thus showing a tendency of the current to spread laterally as well as vertically, but more largely vertically.

The immediate area around the electrodes was more affected than that further remote. There was an area of tissue about 5 inches long between the large and small oval burning that was uninjured, showing that burning was confined about the electrodes. The current traversing the film of water on the bark between the electrodes was not sufficient to destroy all of these tissues at that point.

If a milliammeter had been placed in the circuit when the tree was wet a greatly increased current would have been detected, since the current in this case traversed the less resistant film of moisture on the bark. But the electrical resistance of the vital layer under such conditions would remain practically the same as when the tree was dry. The burning and injury in this case resulted from the heating of the film of moisture, which became so intensely heated that the vital tissue was destroyed, especially near the point of insertion of the electrodes. The more the film became heated the greater was the lessening of the resistance and increase of the current.

Practically all of the burning of trees from either alternating or direct currents occurs in this way, since the high electrical resistance characteristic of trees does not permit injurious currents to pass through their tissues.

#### DEATH OF TREES FROM DIRECT CURRENT.

Instances are known in which large trees have been killed by direct currents used in operating electric railroads. So far as we know attention was first called to these cases in Bulletin No. 91, issued by this station, but since the publication of this bulletin other cases have been observed in which the escaping current had burned and girdled the trunks for a distance of 5 to 10 feet from the base, the point of contact of the feed wire with the limb 18 or 20 feet above, showing little or none of the characteristic local burning effects usually observed in ordinary cases of grounding. In fact, the difference between the burning from direct currents in these cases and that from ordinary cases of electrical injury may be seen at a glance. On electric railroad systems the so-called positive current almost always traverses the overhead feed wire where the injury (burning) takes place. This differs only slightly from that produced by low-tension alternating current wires. In all cases of death from direct current electricity that have come to our notice the rail was positive, and the overhead feed wire was negative, constituting what is called a "reversed polarity." How common this practice is we cannot say, but apparently it has been done inten-

tionally at times to prevent electrolysis as well as unintentionally by various companies, and is responsible in quite a few instances for the death of shade trees near electric railroads. There is much greater opportunity for extensive burning in the case of reversed polarity than in the regular systems employed. The moisture conditions of the soil and bark are such as to reduce the resistance, and in consequence the film of water and water-soaked bark become intensely heated, destroying the living tissues and girdling the tree to a considerable distance. The part of the trunk towards the rail is almost invariably the most severely affected. In the cases observed some years ago, where the current was reversed, there were no deep burning effects on the tree either above or below, — the rule when the overhead feed wire is positive (as is usually the case) and in direct contact with the tree. Moreover, the affected areas about the base of the tree are decidedly larger than when a positive overhead feed wire comes into contact with limbs. The entire area between the base of the tree and the overhead wire is not, as a rule, affected, although the extent of injury may vary somewhat. The injury from burning is confined to a space around the overhead wires, and also to the base of the tree. On the elm shown in Fig. 8, Plate IV., the burning was caused by a reversed system, and there was only slight injury at the point of contact with the overhead wire, while at the base about 6 or 7 feet of the tree was affected. This injury takes place when the soil and bark of the tree are moist, and may occur during a single period of excessive moisture, or intermittently. In some instances trees show serious effects a short time after the current has been reversed, when the bark will become loose and later fall off. The writer has observed both elms and maples — some of them 2 feet or more in diameter — which have been killed in this way. In some cases the trees were not more than 3 feet from the rails, while in others the distance was considerably greater.

In one well-planted city having extensive street railways, 51 trees were reported killed or so badly injured as to be of no value, 67 had large limbs removed, and many more were saved by removing limbs likely to come into contact with the wires. According to Mr. G. A. Cromie,<sup>1</sup> who had these under observation, the injured trees were in some cases located from 200 to 1,000 feet from the track. Some of the injury took place on streets having wires but no electric railways, and it is surmised that the ground connections were made through several pipe lines, located near the trees, which led very close to the electric railway. Mr. Cromie states that the effects on the trees were noted shortly after the street railway had changed its system, *i.e.*, using the rail to carry the positive, and the overhead wire the negative or return current. The trees in contact with the overhead wire became electri-

<sup>1</sup> G. A. Cromie, "Scientific American" supplement, No. 1985, p. 40, Jan. 17, 1914.

cally charged, and when wet it was impossible for linemen to work on them. Under these conditions the insulation was much less efficient, and even wooden sleeves imbedded in coal tar and rubber proved of small use in preventing leakage, but otherwise there was little or no trouble from burning.

We were able to examine only a few of these trees, most of them having been removed at the time of our observations; but a large percentage showed a characteristic burning at the base and the bark was burned off in some instances to quite an extent. One limb that had been in contact with the negative feed wire was found dead, but the tissue at the base of the trunk was normal. Dr. J. W. Toumey, director of the Yale Forestry School, who examined many of these trees, found a disintegration of the wire where it came into contact with the limbs, apparently due to electrolytic action, and chemical analysis showed the presence of copper and zinc in the tissues of the wood that had been in contact with the negative or overhead wire. Dr. Toumey believes that in such cases the disintegration of the copper wire and the absorption of the copper by the tissue were responsible for the death of the limbs. If true, this entirely new state of affairs would indicate that the electrical injury from direct currents not only arises from heat but also from the electrical disintegration of metals, which may poison the tissues. These observations demonstrate that we have a variety of conditions to deal with in considering the effect of direct current electricity on trees, and these phenomena may be summarized as follows:—

Burning and injury to plant tissue are much more noticeable at points with a positive potential<sup>1</sup> than at points with a negative potential.

When the rail is at a positive potential the overhead wire, which touches some part of the tree, is negative, and the bark and soil are saturated with moisture, and a circuit is formed by means of this surface moisture.

The moisture conditions and the electrical resistance, etc., at the base of the tree are different from those above, therefore a larger area of tissue is affected by the positively charged rail.

As the bark becomes heated through the film of water, the electrical resistance is reduced and the current increased to such an extent that the vital layer is destroyed.

The actual current passing through the inner tissues must necessarily be insignificant, and when there is a film of water on the bark, probably no current passes through the cambium; furthermore, the moist soil between the rail and the trunk of the tree becomes a better

<sup>1</sup> Positive electro-static charges have a more stimulating effect on plants than negative charges, and retardation of growth and injury to the cells are more pronounced. The phenomena associated with the positive and negative galvanotropic bendings of roots may be explained in this way (24th Ann. Rept. Mass. Agr. Exp. Station, Pt. I., p. 144, 1912).



conductor for the current than the roots. The actual injury, therefore, is done by the current traversing the film of water rather than any of the inner tissues. The maximum heat and the areas most affected are near the base of the trunk.

In regard to the possibility of injury to large trees by direct currents passing directly through them, experiments show that what holds true for alternating currents is true also to a great extent of direct currents. However, it would require a voltage much higher than that furnished by most electric railways at the present time.

It might be possible for direct currents to produce a weakening effect on the vital activities of the tree, although not causing any perceptible burning. If, for example, a tree was subjected to a strength of current equivalent to that represented between R and MX in Fig. 3, page 2 (retardation current), there might occur a disintegration of the cell contents, causing the tissues to become abnormal and finally die, but the electrical resistance of trees is so great that a quite high potential would be necessary. If the potential of the electric railway systems were increased ten or twenty times it is possible that some injury might result to trees even under ordinary moisture conditions.

Probably the amount of ground leakage occurring through imperfect rail connections would not cause any perceptible injury to trees. Nor is there any direct evidence that lightning arrestors when placed near trees cause any injury by discharges. However, the guy wires used by electric railway systems are a source of danger from lightning, and we have observed cases where large limbs have been destroyed and the trunks of the tree badly lacerated by electrical discharges from these wires.

On the whole, the cases of death to trees from electricity are by no means so numerous as is generally believed. Because a large number of trees near electric roads, etc., often look sickly it must not be concluded that electricity is always the cause. In cities and towns, where most of these unhealthy specimens are found, there are innumerable destructive factors for trees to contend with. It is quite essential in diagnosis work, therefore, that all of these factors be taken into consideration before a definite opinion in regard to the cause of any abnormal condition is formed.

#### ELECTROLYSIS.

Direct current electricity is frequently responsible for electrolysis of gas and water mains, and lead coverings of underground telegraph circuits are often affected. The trouble is often so serious that the iron gas and water pipes (Fig. 9, Plate III.) become corroded and eaten with holes in a few weeks or months, causing leakage. When gas mains are affected by electrolysis, the gas escapes and permeates the soil, so

that electricity sometimes becomes a primary and gas a secondary factor in the death of trees.

The phenomena associated with electrolysis are often complex and difficult to do away with entirely, according to expert electricians, but much of the trouble can be eliminated by proper bonding of the rails of electric roads and the grounding of different systems.

Electrolysis is more common in wet than in dry soils. Cases are on record where severe electrolysis has taken place 700 or more feet from the source of leakage. It more often becomes troublesome in cities where numerous railways and public-service corporations of all kinds make use of the streets. We have observed cases where plants have been stimulated and their growth increased by escaping electricity in the soil.

#### LIGHTNING.

The common effects of lightning strokes on trees are so well known that it is not necessary to dwell upon them here; but lightning does not always strike a tree in the same way, and the peculiar effects sometimes produced are often interesting. Very powerful discharges of lightning act somewhat like an avalanche, causing a severe shattering of the tissue, while less powerful discharges may remove a strip of

wood only a few inches wide and 1 or 2 inches thick. Lightning often takes a spiral course, following the grain of the wood, which is sometimes very irregular. Even when strips of wood 4 or 5 inches wide and 2 or 3 inches thick are removed, in which case the electrical energy is enormous, the path of the discharge is shown only by a dark-colored streak 2 or 3 millimeters wide.



FIG. 11. — Cross-section of elm shown in Fig. 10; X = small dead area corresponding to path of lightning discharge.

Sometimes trees are killed outright by lightning without being shattered or displaying any other of the common effects. In such cases the discharge is apparently dispersed so as to cause no visible mechanical injury to the tree, but the girdling of a large or small area of the living zone or cambium layer of the trunk would be sufficient to cause its death. However, in a very large number of instances neither death nor mechanical injury

of any importance takes place. Hundreds of trees are annually struck by lightning that never show any effects except to those capable of interpreting the small narrow ridges which later make their appearance on the trunk. (See Fig. 10, Plate V.). In such cases the lightning discharge follows the line of least resistance,—the cambium zone,—burning a small channel usually about 1 millimeter in diameter. The

tissues surrounding the channel are apparently not injured, but the annular rings which are later formed outside the burned channel are much broader, resulting in the formation of a ridge on the bark. (See Fig. 11.)

#### *Earth Discharges.*

There are many cases of lightning that are apparently earth discharges. Their effect on the tree is quite characteristic and not at all similar to the ordinary forms of lightning strokes. Our attention was called several years ago to some shade trees to which lightning had apparently caused some injury. These trees were maples 5 to 18 inches in diameter, growing in soil composed mainly of gravel containing oxide of iron, and underneath this a stratum of quicksand. A considerable number of the trees showed the effects of repeated earth discharges, in some cases becoming so disfigured that they had to be replaced for the third time. These discharges occur during thunder storms, and those who have observed them for many years relate that they give rise to a dull, characteristic report resembling that caused by throwing a wet cloth on a hard surface. The whole tree is not affected as a rule, as the lightning stroke seldom follows up the main trunk, but discharges at the points of several branches. As a rule, however, one side of the trunk and one or more of the limbs on that side are affected and the symmetry of the tree destroyed. The first indication of the discharge is shown by the immediate wilting and subsequent death of the leaves of the affected limbs, which also die later. In the course of time cracks similar to those caused by frost, and later, ridges due to healing, will be seen on the trunk, showing the path of the discharge, and occasionally when the injury is considerable the bark falls off near the affected part of the tree. The limbs, however, are not always killed, frequently splitting (see Fig. 12, Plate V.), and a cracking of the wood for some depth is now and then observed on the trunk and limbs along the path of discharge.

A very much larger number of trees show earth discharges than is realized. MacDougal<sup>1</sup> has called attention to some trees which appear to have been injured by earth discharges.

Whether the chemical composition of the soil has any particular bearing on earth discharges is not positively known. It is known, however, that there frequently exist great differences in the electrical potential between the earth and air during thunder storms, and that the electrical conditions of the atmosphere and earth may change instantly from negative to positive. Some observations made in our laboratory with a Thomson self-recording quadrant electrometer and

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<sup>1</sup> Journal of the N. Y. Bot. Gardens, Vol. III., No. 31, July, 1902.



water-dripping collector show that the electrical potential of the atmosphere varies from a negative charge of 75 volts to 300 positive at various times at a distance of 30 feet from the ground; and our records show that most of the time the atmosphere is charged positively. It is also known that trees occasionally discharge sparks at their apices, showing that insignificant earth discharges occur through trees; and when the soil in which potted plants are growing is charged electrostatically, small sparks are thrown off from the leaves. Earth discharges through trees, whether strong or weak, appear to be similar in nature, and may be associated with changes in the potential of the earth and atmosphere. The high electrical resistance shown by plants in general, as already stated, serves as a great protection against death from lightning and electric currents.

*Susceptibility of Different Trees to Lightning Stroke.*

There has always been great difference of opinion in regard to the susceptibility and non-susceptibility of various trees to lightning, and the data on the subject gathered from this and that source are altogether too meager to admit of reliable statistics. But it is known that the location of the tree, nature of the soil, elevation, etc., are of great importance in determining susceptibility to lightning.

It has already been pointed out that electrical resistance is influenced by temperature, and the percentage of moisture in the tissues is also an important factor. During thunder showers trees become more or less drenched with rain, and according to Stahl,<sup>1</sup> the more thoroughly wet the tree is the less susceptible it becomes to lightning stroke. He bases his observations on the fact that smooth-bark trees like the beech and others, which are considered more immune to lightning, become thoroughly wet during storms, while the oak and other rough-bark trees do not. Stahl's idea, therefore, is that smooth-bark trees possess a better water-conducting surface and have a tendency to equalize the electrical tension existing between the atmosphere and the ground, so that they are rendered less susceptible to lightning. His deductions were based upon experiments with electrical discharges made with the bark of different species of trees containing various percentages of moisture. He further observed that vertical limbs were more likely to become drenched than horizontal, and that the lenticels and stomata play a rôle in the equalization of the differences in electrical potential existing between the tissues and the atmosphere, etc. There appears to be no difference in the electrical potential under deciduous trees and in the open air when there is no foliage, at corresponding heights, and the electrical potential will average 40 per cent. less under the foliage of trees than in the open air when the foliage is developed.

<sup>1</sup> Stahl, E. Die Blitzgefährdung der verschiedenen Baumarten, Jena, G. Fisher, 1912.

The potential of the air is usually negative, although occasionally changing to positive. In the case of coniferous trees, however, like the Norway spruce,<sup>1</sup> we found that the potential under the foliage was invariably positive or similar to that of the earth, which may be explained on the theory that conifers are constantly discharging positive electricity to such an extent that the air surrounding them becomes charged similar to the earth. To what extent the film of water on the bark is capable of equalizing the difference in electrical potential in the air surrounding the trees, as well as the ground and in the tissues themselves, has not been wholly determined, but we had difficulty in obtaining potential readings under the foliage of elms in wet weather in our experiments covering two summers. This may in part be explained by the improper installation of our collector. It is not unlikely that the film of water on the bark of trees during such periods would have a tendency to affect materially the potential of the surrounding air, and possibly to equalize the electrical tension. The subject should have further investigation, but we believe that it is possible to protect trees from injury by lightning, whether they be atmospheric or earth discharges.

#### METHODS OF PREVENTING INJURY TO TREES FROM WIRES. ✕

The constantly increasing use of electricity for various purposes makes necessary a more extensive use of wires which have become a great menace to shade trees. The appearance of streets is also hardly improved by the increased number of poles and wires, and the legal restrictions as to the height, distance apart, etc., of the wires of the telephone, telegraph, trolley and electric light companies make the problem of maintaining shade trees on the same street with public-service corporations a serious one. Of all the troubles with which tree wardens have to contend the wire problem is often regarded as the worst. Notwithstanding the strict laws which some States have adopted in regard to injuring shade trees, the agents of some public-service corporations often have little regard for trees or the laws respecting them. Where 40-foot poles must carry the wires of three or four public-service corporations there can be little or no opportunity to preserve the natural symmetry of shade trees, especially when low branching maples and other trees are planted on the same side of the street with the wires. There is less interference from limbs with low than with high-tension wires. Trees like the elm, whose branches form acute angles, offer less obstruction to wires than maples; but not all streets, of course, are planted with elms, which may be as well, considering their susceptibility to various pests and unfavorable climatic conditions.

The best solution of the wire problem lies in burying the wires. This

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<sup>1</sup> Mass. (Hatch) Agr. Exp. Sta. Rept. 1905, p. 14.

has been done to quite an extent in large cities, especially in the business sections, the telephone corporations having adopted this system to a much greater extent than the electric light companies. It is an expensive system, however, and those who so strenuously advocate its adoption do not always consider that in the end it is the patrons who have to pay for it.

Another method of preventing wire injuries is the erection of high poles to bring the wires over the trees. This is sometimes done, especially where the trees are young or of a species that naturally grows low, when a very high pole would be sufficient to clear them for many years. The cable system may be used for telephone wires, and much injury to trees prevented. Large cables are rather expensive to install,

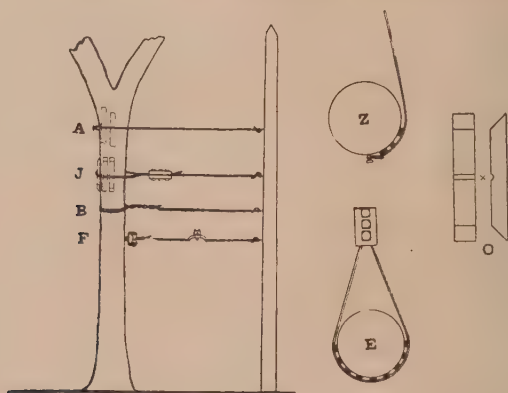


FIG. 13.—Showing different methods of attaching wires to trees: *a*, wire attached to lagbolt, and tree protected from it by wooden blocks; *z*, cross-section of same; *b*, wire loops placed tightly around tree, causing girdling; *f*, showing attachment of trolley guy wires; *j*, loose loop fastened with clamps and separated from tree by blocks; *e*, cross-section of same; *o*, creosoted oak blocks with groove *x* to support the wire.

but what is termed the "ring construction" system may be used to advantage in many instances, particularly in the suburbs. In this way it is possible to run a line through avenues of fine trees in the country districts without necessitating pruning or disfiguration.

Rights of way for poles on private property back of residences are sometimes secured, and by this means the poles and wires may be removed from the streets, much to the advantage of the trees. But such rights are often difficult to secure, and are not always satisfactory either to the public-service corporations or the owners of the property. The former naturally do not care much for these rights of way unless they are legal and permanent, and the owners in granting permanent



rights run a risk of lowering the value of the property. Most of the very high-tension transmission services, however, are at present on private property and seldom interfere with trees. High-tension lines are affected seriously merely by close proximity to trees; therefore these rights of way have to include broad strips of land, which of course is expensive.

On general principles it is not wise to allow wires to be attached to trees, although this is often done. Trolley and electric light wires are frequently guyed to trees, but they are a source of danger, since injury is likely to occur from the crossing of the wires, and lightning discharges occasionally pass from the wires to the tree, causing damage.

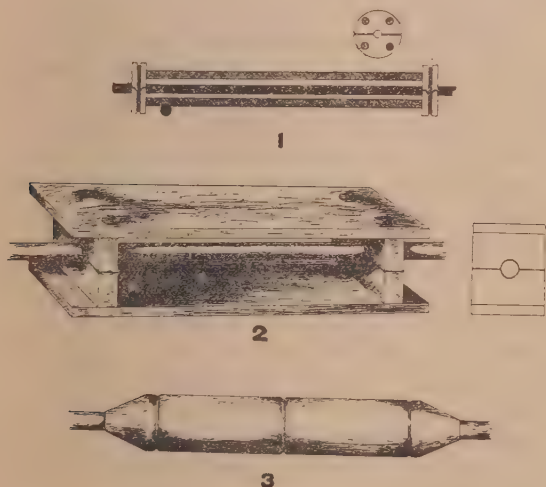


FIG. 14. — Showing different types of guards for electric wires: 1, porcelain dowel guard; 2, porcelain wood guard; 3, wooden sleeve.

It is, however, often better to allow this than to endure the erection of ugly poles; but proper insulation of the wires should be insisted on, although ordinary insulators have little effect on lightning discharges. The lagbolt system in common use for guying wires to trees is not the best method, for sooner or later the wire and bolt become imbedded in the tree and cause injury. Moreover, a direct metal connection with a tree is objectionable, as it has in more than one instance proved. The block system is better, although it may not in all cases be free from objections. In no case should a wire be allowed to pass tightly around a tree, as it will girdle it in time. When live wires come into contact with limbs, some type of insulator should be employed similar to that shown in 1, Fig. 14, of which there are various types, some being quite effective in preventing injury from low-voltage lines. The type shown

in Fig. 14, No. 2, is cumbersome and unsightly, but is one of the most effective. The principle of the porcelain and dowel insulator is good, but it has a tendency to slide on the wires and become displaced. If it were provided with larger dowels, and the danger of displacement on the wires done away with, it would prove much more satisfactory.

Wires often accidentally come into contact with trees by the displacement of poles, particularly on curves, where the strain is very great, but much of this injury may be prevented by imbedding the poles in Portland cement. It should be pointed out that the necessity for guying poles to trees may be obviated in this way.

Better methods of handling this vexatious question of wires and shade trees should be forthcoming in the future, and even at present there must be a compromise between the tree warden or city forester and the companies as to the best method of wiring through tree belts and the amount of pruning allowed. Conditions at present favor the corporations, as they are furnishing valuable and necessary facilities for business, etc., and in towns they obtain their franchises and location of poles from the selectmen with little difficulty. The selectmen notify the abutters of any contemplated installations of poles and wires or of changes to occur in the systems, and the abutters are given a hearing. However, they usually wake up to their duty only after the installation of the lines, when the tree warden must assume all responsibility for injury to the trees. He has to choose between two courses, — prevent the pruning or permit it. In either case the companies can erect the poles and install the wires, allowing the wires to burn their way through the trees, although this, of course, often causes trouble to the corporation as well as to the consumer. In case of injury to trees the warden has access to the courts, but most companies are willing to put up with a few moderate fines for the sake of the right of way through a tree belt.

#### SUMMARY.

Electricity acts as a stimulus to plants. The minimum and optimum current strengths probably differ little in different plants. The maximum current, or that necessary to kill a plant, is quite variable.

Outside of the disfiguration to trees from pruning necessitated by wires, the greatest injury consists in the local burning and often partial destruction of the tree caused by high-tension line wires.

There is practically little or no leakage from wires during dry weather. In wet weather, however, when a film of water is formed on the bark, more or less leakage occurs, and if the insulation is insufficient, grounding takes place and burning, due to "arcing," results.

No authentic cases have been observed by us where the alternating or direct currents as ordinarily employed have killed trees; but instances are known in which the death of trees has taken place when

the polarity in electric railway systems have become reversed; *i.e.*, the rail becoming positive and the feed wire negative.

The burning is more pronounced at the positive electrode than at the negative, and when the current is reversed a larger area of tissue is affected. The burning arises from the heating of the film of water on the bark, which destroys the live tissue underneath.

The high resistance offered by trees and plants in general serves as a protection against severe injury from lightning and contact with high-tension line wires.

The least resistance in trees occurs in the vital layer (cambium) and adjacent tissues.

The electrical resistance of trees is influenced materially by temperature and moisture.

The physiological effect of the direct current on vegetable life differs from that of the alternating.

There is evidence to support the idea that a direct current of not sufficient strength to cause burning may electrolyze the cell contents and later result in the death of the tree.

Earth discharges during thunder storms are more common than generally supposed, and are known to disfigure and cause the death of trees.





PLATE I.



FIG. 1.—Showing maple tree injured by lightning discharge from trolley guy wire, causing death of limb and laceration of trunk.



FIG. 2.—Showing the destructive effect on the growth of a maple tree of a mass of wires.





PLATE II.



FIG. 4.—Showing injury to young maple tree by linemen's spurs.



FIG. 5.—Showing the effects of strangulation by wires.



PLATE III.



FIG. 6.—Showing disfigurement of trees caused by high-tension alternating current wires.

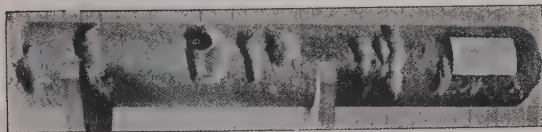


FIG. 9.—Showing electrolysis of gas pipes. (After A. A. Knudson, "Corrosion of Metals by Electrolysis.")





PLATE IV.



FIG. 7.—Showing deep burning of large limb by high-tension alternating current wire.

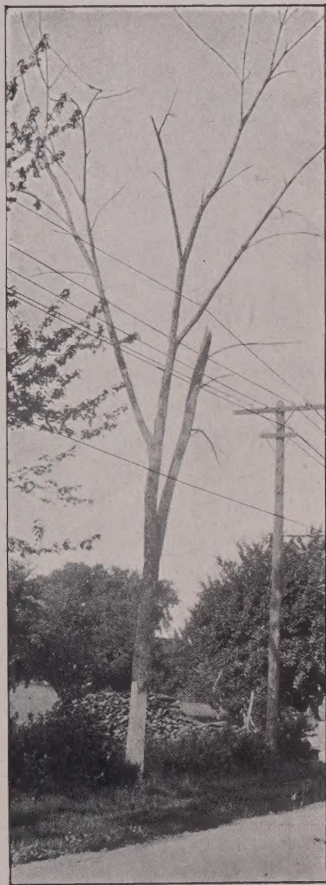


FIG. 8.—Showing elm tree killed by direct current (reversed polarity) from electric railway system. Note effects of burning at the base of the tree.





PLATE V.

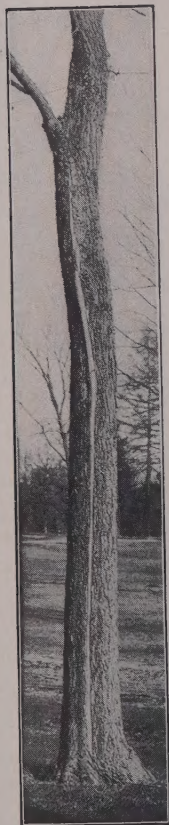


FIG. 10. — Showing ridge on elm tree caused by feeble lightning discharge.

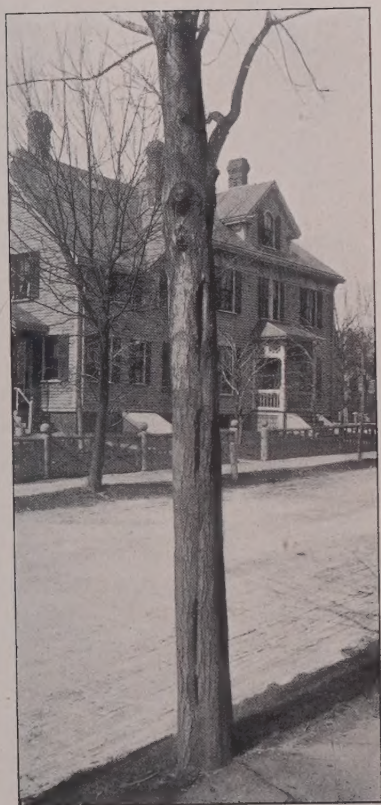


FIG. 12. — Maple showing effects of earth discharges (lightning), causing splitting of the trunk and death of limbs.

